RESPONSE OF CERTAIN WINTER WHEAT VARIETIES TO STAND DENSITY

by

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INTRODUCTION

Seeding rate has long been considered important in winter wheat culture. Today seeding rates have been well established in the major wheat producing regions. Since these seeding rates are based largely on older studies, it is of interest to determine if they are satisfactory for recently developed varieties.

Optimum seeding rates and the responses to various rates for varieties known to differ rather widely in morphology are worthy of study, since little information is available. Consideration of varietal reactions to sub-optimum seeding rates is also important.

Another point of interest is the influence of plant density on the yield components (heads per unit area, seeds per head, seed weight) of different varieties and the importance of each component in determining yield.

The performance of varieties in space planted studies in relation to field performance is of particular interest to the plant breeder.

The present study was undertaken to investigate the influence of seeding rate and plant spacing on yield and yield components of six winter wheat varieties.

LITERATURE REVIEW

Seeding Rate

The optimum rate for sowing winter wheat has long been the object of much research. In 1888, Hickman (15) reported five to seven pecks per acre to be the optimum seeding rate in Ohio. Two or three pecks were inferior while there was a slight reduction in yield with eight or nine pecks. In Indiana, Latta (21) found that six to eight pecks per acre produced maximum yield. Four or five pecks resulted in slightly lower yield, and two or three pecks caused a sharp reduction in yield. In Illinois, Morrow and Gardner (31) found four to eight pecks per acre to give about the same yield and suggested that five pecks were adequate. Three pecks resulted in yield considerably below those from the higher rates. Georgeson (10) reported eight pecks per acre to be the optimum seeding rate in an early eastern Kansas study. However, later work by Ten Eyck and Shoesmith (42) and Stickler (41) shows five or six pecks to be adequate in eastern Kansas.

Early work showed the optimum seeding rates for drier areas to be somewhat lower than those for the more humid regions. Morrow and Bone (30) found four to six pecks per acre to produce maximum yield in central Oklahoma. In Nevada, McDowell (28) reported five to six pecks per acre to be the optimum seeding rate. Moss (32) found four pecks per acre to produce maximum yield in an Idaho study. Seeding rate recommendations in New Mexico were two and one-half to three and one-half pecks per acre under dry farming conditions and four to six pecks under irrigation (40).

Later work has produced about the same results as that found by the earlier workers in this country. Optimum seeding rates in drier regions are considered to be from four to six pecks per acre (5,19,22,26,27). However, some work has shown that the optimum seeding rate in drier areas may be as high as eight or as low as two pecks per acre (38,39,41). In the more humid regions, seeding rates of five to nine pecks per acre are considered to produce maximum yields (2,24,25,27,34,43).

Winter wheat seeding rates in other parts of the world differ little from those used in comparable areas of the United States. In Ontario, Canada, Zavitz (45) reported six to seven pecks per acre to be the optimum rate. Glynne and Slope (11) reported twelve pecks per acre to produce maximum yields of two varieties in a three year test in England. However, in reviewing English data, Percival (35) and Boyd (3) concluded that the optimum seeding rate in that country is about eight pecks per acre. Four to six pecks per acre was considered by Forster (9) to be the optimum seeding rate in most of Australia.

One obvious fact brought out by most winter wheat seeding-rate studies is that there may be a relatively wide range in rates without materially effecting yield (24,27,31,36,43). However, using seeding rates below the optimum usually produces a much larger reduction in yield than does an equal amount above the optimum (3,19,21,26,30,31,43). Rates below three pecks per acre in the drier areas and below four pecks in the more humid areas of this country have been shown to be almost always inferior to higher rates (10,15,19,24,25,26,31,43).

The relatively wide range of seeding rates used in any one general location can be largely explained by the ability of the wheat plant to adjust by tillering and changes in head size and seed weight (5,13,26,34). However, many other factors have important roles in determining seeding rates. The variety, kernel size, germination percentage, and seedling vigor of each lot of seed contribute to the actual stand established (10,16,24,35). Seedbed preparation and the method and time of sowing must be considered (17,35). Climatic differences from year to year and soil type and fertility variations from field to field are also important factors influencing seeding rates (3,4,16,35).

Plant Spacing and Yield Components

Grantham (12) studied ten varieties at spacings of 10, 20, and 40 seeds per foot of row. Depending on the variety, plants grown at ten seeds per foot had two to three times as many heads per plant as those grown at 40 per foot. The yield per head at the thinnest spacing was almost twice that at the thickest. In another experiment, Grantham (13) found that increasing the seeding rate from four pecks per acre to eight pecks decreased the number of heads per plant about 40 per cent and the yield per head was reduced about 25 per cent. Yield per plant was reduced about 48 per cent. The yield per acre was about the same for both rates.

Montgomery (29) showed that although the number and size of heads per plant and yield per plant rise rapidly with increased area per plant, the yield per unit area of land may decrease.

He studied spacings of two, one, one-half, and one-fourth inches per plant in eight inch rows. The yield per plant at the two-inch spacing was 4.10 grams compared to .91 grams for the one-fourth inch spacing. However, the yield per plot was 165 grams for the two-inch spacing and 238 grams for the one-fourth inch spacing. Percival (35) obtained similar results with plant spacings ranging from 6 x 1 to 24 x 24 inches. The number and size of heads and yield per plant increased with increased spacing; however, the yield per acre dropped rapidly due to reduced plant population. Buffum (4) and Nelson (33) reported similar results with spring wheat. Wilson and Swanson (44) found that lowering the plant population below fifteen plants per square foot resulted in a significant reduction in yield per acre.

The number of seeds per head has been shown to increase as plant density is decreased or as the number of heads per square foot is decreased (1,5,8,35,41).

Test weight was found to increase with increased plant population by Wilson and Swanson (44). Kinra _et al_. (20) reported test weight to increase slightly with higher seeding rates in two tests while there were no significant differences in two other tests. Zavitz (45) found no significant changes in test weight due to seeding rate.

In general, weight per kernel increases with increased plants per acre (5,12,13,14,31). However, others have reported no influence of seeding rate on kernel weight (8,24,44). Stickler (41) reported a reduction in kernel weight with increased seeding rate one year and a rise the next year. Ahmed (1) found a slight

decrease in kernel weight as seeding rate was increased.

High seeding rates often result in hastening maturity (4,13, 44). Plant height may be decreased by increasing plant population (4,5,13,44).

There may be considerable varietal differences in response to seeding rate or plant spacing (8,12,13,14). In extensive seeding rate and plant spacing studies with a large number of varieties, Grantham (13) found wide differences in the tillering and yield responses of different varieties. However, Ahmed (1) reported the influence of various seeding rates and plant spacings to be similar for six varieties in a one-year study. Guitard (14) found only slight differences in the response of two varieties of spring wheat to seeding rates at three locations.

Kinra _et al_. (20) and Ahmed (1) reported a decrease in protein content of grain as plant density was increased. However, Pendleton and Dungan (34) found seeding rate to have no effect on grain protein and Kiesselbach _et al_. (18) reported an increase in protein with increased seeding rate.

METHODS AND MATERIALS

During 1962-63, a seeding rate and a plant spacing study with winter wheat was conducted on the Agronomy Farm at Manhattan, Kansas.

The experiments were conducted on a light silty clay loam soil having an unusually thick (16 to 24 inches) A horizon. The preceding crop was oats. A mixture of 16-48-0 and 33.5-0-0 fertilizer providing approximately 49 and 20 pounds of nitrogen (N) and phosphorus (P), respectively, per acre was applied prior to planting. Planting was done on October 9 with Planet, Jr., 300-A seeders. Germination of the seed was determined in order to accurately calibrate the various seeding rates.

Both experiments were conducted in a split plot design with four replications. The main plots were the six winter wheat varieties: Bison, Cheyenne, Kaw, Ottawa, Pawnee, and Triumph. The sub plot treatments in the seeding rate experiments were seeding rates of 6, 12, 18, 24, and 30 viable seeds per foot of row (12-inch rows). These rates were equivalent to approximately 30, 50, 70, 90, and 110 pounds of seed per acre, respectively. The final stands of Bison, Cheyenne, and Triumph were slightly below the stands of the other three varieties. In the plant spacing experiment, the sub plot treatments were spacings of 6, 9, 12, and 15 inches between plants in the row (12-inch row). This experiment was seeded at approximately 30 pounds per acre and the plants were thinned by hand to the desired stand.

Each sub plot consisted of four 12-foot rows. Nine feet of

the two center rows were harvested for yield. Head counts were made from a three-foot section of the center rows in the seeding rate experiment. In the space-planted experiment, the heads on five plants were counted. Weeding was done in April.

The wheat was harvested by hand, dried, threshed, and weighed. Seed weight was determined by counting and weighing 200 seeds from each sub plot. The number of seeds per head was determined from seed weight, heads per square foot, and sub plot yield data. After grinding, the protein percentage of the grain was determined by the Kjeldahl method. Percentages were determined on an oven-dry basis. Statistical analysis was done according to procedures outlined by Snedecor (37) and LeClerg _et al_. (23).

EXPERIMENTAL RESULTS

Seeding Rate Experiment

Sources of variation, degrees of freedom, and mean squares in the analysis of variance for the seeding rate experiment are given in Table 1.

Yield Per Acre. The yields for the different variety and seeding rate combinations are given in Figure 1 and Table 2. Analysis of variance showed that differences among varieties and among seeding rates were significant at the one per cent level of probability. The yields of Ottawa and Kaw were significantly (five per cent level) higher than those of Triumph and Pawnee. Bison and Cheyenne yielded significantly less than Ottawa, Kaw, Triumph, and Pawnee. Highest yields of Cheyenne and Triumph were produced at the seeding rate of 24 viable seeds per square foot while the maximum yields

Table 1. Sources of variation, degrees of freedom, and mean squares in analysis of variance of data from the seeding rate experiment.

Source	D. F.	Mean Squares				
		Yield (lbs./A.)	Heads per sq.ft.	Seeds per head	Seed weight (g./200)	Protein Percentage
Main plots						
Replications	3	54,228	165.2	73.43	.020	.523
Varieties (V)	5	2,623,752**	535.6**	10.77	11.970**	1.324**
Error A	15	47,405	83.9	42.51	.029	.286
Sub plots						
Rates (R)	4	2,383,485**	138.6**	45.52**	.063	.488**
V X R	20	103,568**	10.5	10.23**	.018	.246*
Error B	72	27,474	18.7	3.74	.057	.134
Total	119					

* Significant at 5% level

** Significant at 1% level

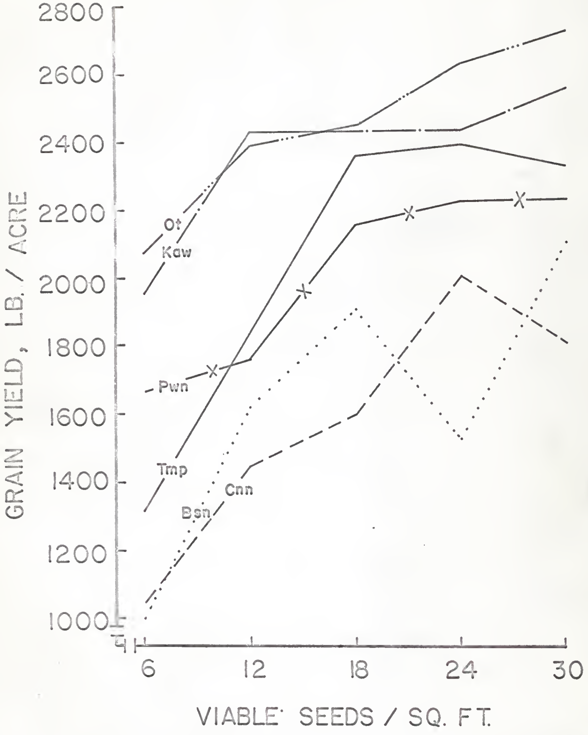

Figure 1. Influence of variety and seeding rate on grain yield.

Table 2. Influence of variety and seeding rate on grain yield (pounds per acre).

Variety	Viable seeds per sq. ft.					Variety mean
	6	12	18	24	30	
Bison	998	1616	1907	1521	2110	1630
Cheyenne	1040	1447	1597	2005	1810	1580
Kaw	1960	2430	2432	2432	2562	2363
Ottawa	2078	2392	2455	2633	2730	2458
Pawnee	1671	1760	2151	2228	2234	2009
Triumph	1314	1836	2357	2382	2338	2045
Seeding rate mean	1510	1914	2150	2200	2297	

LSD at 5% level

Varieties = 147

Rates = 95

Varieties within each rate = 255

Rates within each variety = 74

Variety	Ottawa	Kaw	Triumph	Pawnee	Bison	Cheyenne
Ranking	2458	2363	2045	2009	1630	1580

Rate	30	24	18	12	6
Ranking	2297	2200	2150	1914	1510

Means underscored by the same line are not significantly (5% level) different.

of Bison, Kaw, Ottawa, and Pawnee were obtained with 30 viable seeds per square foot. Kaw, Ottawa, and Pawnee gave increased yield with each increase in seeding rate. Triumph yield increased rapidly as the seeding rate was increased to 18 viable seeds per square foot and then showed little difference at 18, 24, and 30 viable seeds per square foot. In comparing the yield of these varieties, it should be remembered that the actual field stands of Bison, Cheyenne, and Triumph were somewhat less than those of Kaw, Ottawa, and Pawnee.

There were significant increases in yield as the seeding rate increased with the exception of the increase from 18 to 24 viable seeds per square foot. The largest single increase in yield occurred between the 6 and 12 viable seeds per square foot rate.

The variety x seeding rate interaction was significant at the one per cent level. Much of this interaction was attributed to the drop in yield at 30 viable seeds per square foot for Cheyenne and the low yield of Bison at 24 viable seeds per square foot. Also, the yields of Bison, Cheyenne, and Triumph were reduced much more by thin seeding than were the yields of Kaw, Ottawa, and Pawnee.

Number Of Heads Per Square Foot. The influence of variety and seeding rate on the number of heads per square foot is shown in Figure 2 and Table 3. Variety and seeding rate effects were both significant at the one per cent level. No significant variety x seeding rate interaction was detected. Ottawa and Pawnee had significantly more heads per square foot than Cheyenne, Triumph, and Bison. Kaw had significantly fewer heads per square foot than Ottawa but did not differ significantly from Pawnee, Cheyenne,

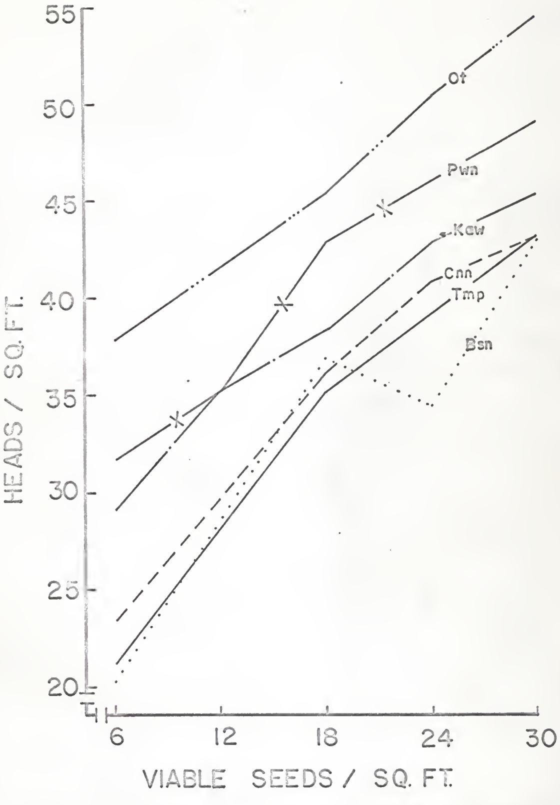

Figure 2. Influence of variety and seeding rate on number of heads per square foot.

Table 3. Influence of variety and seeding rate on the number of heads per square foot.

Variety	Viable seeds per sq. ft.					Variety mean
	6	12	18	24	30	
Bison	20.2	28.6	36.8	34.4	43.0	32.6
Cheyenne	23.4	29.6	36.1	40.8	43.2	34.6
Kaw	29.1	35.3	38.3	42.9	45.3	38.2
Ottawa	37.8	41.5	45.4	50.4	54.5	46.0
Pawnee	31.6	35.2	42.8	46.0	49.1	41.0
Triumph	21.2	28.3	35.2	39.1	43.2	33.4
Seeding rate mean	27.2	33.1	39.1	42.3	46.5	

LSD at 5% level Varieties = 6.2

Rates = 2.5

Variety	Ottawa	Pawnee	Kaw	Cheyenne	Triumph	Bison
Ranking	46.0	41.0	38.2	34.6	33.4	32.6

Rate	30	24	18	12	6
Ranking	46.5	42.3	39.1	33.1	27.2

Means underscored by the same line are not significantly (5% level) different.

Triumph, and Bison. All varieties except Bison showed an increase in heads per square foot with each increase in seeding rate.

A significant increase in heads per square foot was obtained with each increase in seeding rate. The increases in number of heads per square foot as the seeding rate increased from 6 to 12 and 12 to 18 viable seeds per square foot were about twice the increase that occurred from 18 to 24 and 24 to 30 viable seeds per square foot.

Number Of Seeds Per Head. Information on seeds per head is presented in Figure 3 and Table 4. There were no significant differences between varieties, and seeding rate differences were significant at the one per cent level. The seeding rate of 12 viable seeds per square foot resulted in a number of seeds per head significantly higher than the other rates. The 6, 12, and 18 viable seeds per square foot rates produce significantly more seeds per head than the 24 and 30 rates. Thus, in general, the number of seeds per head increased as the seeding rate decreased.

The variety x seeding rate interaction was significant at the one per cent level. This was attributed largely to the inconsistent response of Bison, Cheyenne, and Kaw.

Seed Weight. Figure 4 and Table 5 show the influence of variety and seeding rate on seed weight. Differences due to varieties were significant at the one per cent level while there were no significant differences due to seeding rate. Kaw and Triumph had seed weights significantly greater than the other varieties. The seeds of Ottawa and Bison were significantly heavier than either

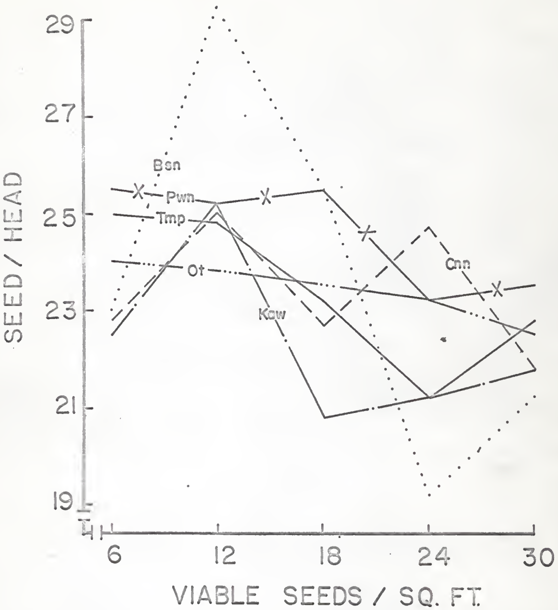

Figure 3. Influence of variety and seeding rate on number of seeds per head.

Table 4. Influence of variety and seeding rate on number of seeds per head.

Variety	Viable seeds per sq. ft.					Variety mean
	6	12	18	24	30	
Bison	23.0	29.2	25.5	19.2	21.2	23.6
Cheyenne	22.8	25.0	22.7	24.7	21.8	23.4
Kaw	22.5	25.2	20.8	21.2	21.8	22.3
Ottawa	24.0	23.8	23.5	23.2	22.5	23.4
Pawnee	25.5	25.2	25.5	23.2	23.5	24.6
Triumph	25.0	24.8	23.2	21.2	22.8	23.4
Seeding rate mean	23.8	25.5	23.5	22.2	22.2	

LSD at 5% level

Rates = 1.1

Rates within each variety = 2.7

Varieties within each rate = 5.0

Variety	Pawnee	Bison	Cheyenne	Ottawa	Triumph	Kaw
Ranking	24.6	23.6	23.4	23.4	23.4	22.3

Rate	12	6	18	24	30
Ranking	25.5	23.8	23.4	22.2	22.2

Means underscored by the same line are not significantly (5% level) different.

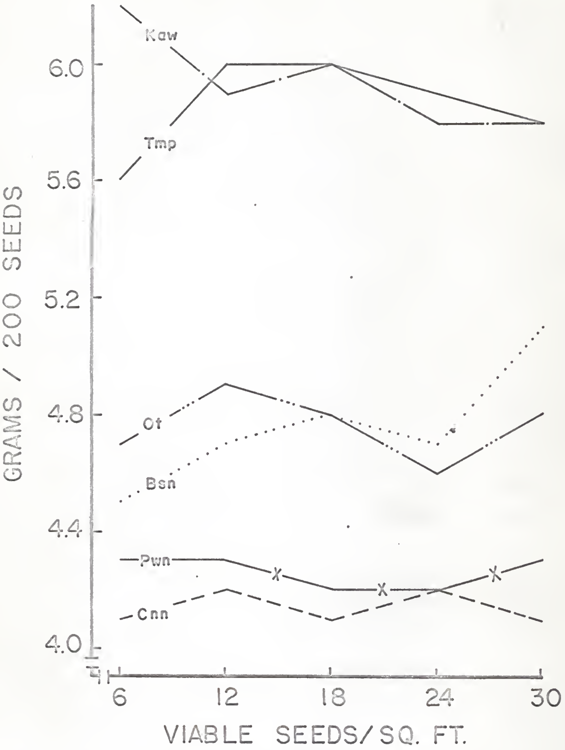

Figure 4. Influence of variety and seeding rate on seed weight.

Table 5. Influence of variety and seeding rate on the weight of 200 seeds (grams).

Variety	Viable seeds per sq. ft.					Variety mean
	6	12	18	24	30	
Bison	4.51	4.74	4.84	4.72	5.11	4.78
Cheyenne	4.06	4.19	4.11	4.19	4.08	4.13
Kaw	6.15	5.86	5.99	5.84	5.84	5.93
Ottawa	4.73	4.87	4.85	4.65	4.83	4.79
Pawnee	4.29	4.32	4.20	4.24	4.34	4.28
Triumph	5.65	6.02	5.96	5.86	5.85	5.88
Seeding rate mean	4.90	4.99	4.99	4.93	5.01	

LSD at 5% level Varieties = .12

Varieties	Kaw	Triumph	Ottawa	Bison	Pawnee	Cheyenne
Ranking	5.93	5.88	4.79	4.78	4.28	4.13

Rates	30	18	12	24	6
Ranking	5.01	4.99	4.99	4.93	4.90

Means underscored by the same line are not significantly (5% level) different.

Pawnee or Cheyenne. Kaw produced its heaviest seeds at the lower seeding rates while Bison showed its highest seed weights at the higher seeding rates. The other varieties showed no definite trends. There was no significant variety x seeding rate interaction.

Protein Content Of Grain. The protein percentage of the grain is shown in Figure 5 and Table 6. Bison was significantly higher than Triumph. The six viable seeds per square foot rate produced significantly more protein than all the other rates. Highest protein content of Bison occurred at six viable seeds per square foot. Cheyenne and Pawnee had highest protein content at the lower seeding rates while the highest protein content of Ottawa occurred at the higher rates. Kaw and Triumph failed to show any trend.

The variety x seeding rate interaction was evident at the five per cent level and was attributed to the inconsistent response of all the varieties.

Plant Spacing Experiment

The analysis of variance of data from this experiment is presented in Table 7.

Yield Per Acre. Varietal differences in yield (Figure 6 and Table 8) were significant at the one per cent level. Yields of Ottawa and Kaw were significantly (five per cent level) higher than those of Triumph, Cheyenne, and Bison. Pawnee was not significantly different from Ottawa, Kaw, Triumph, and Cheyenne but was significantly higher than Bison. All varieties produced less grain per

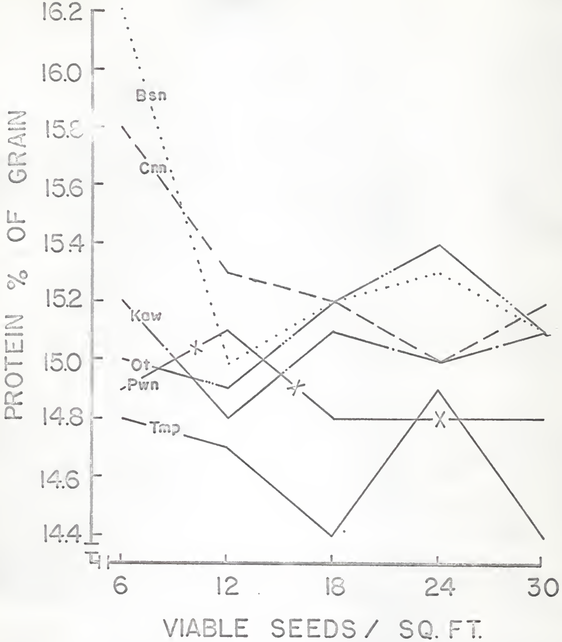

Figure 5. Influence of variety and seeding rate on protein percentage of grain.

Table 6. Influence of variety and seeding rate on protein percentage of grain.

Variety	Viable seeds per sq. ft. 6	12	18	24	30	Variety mean
Bison	16.2	15.0	15.2	15.3	15.1	15.4
Cheyenne	15.8	15.3	15.2	15.0	15.2	15.3
Kaw	15.2	14.8	15.1	15.0	15.1	15.0
Ottawa	15.0	14.9	15.2	15.4	15.1	15.1
Pawnee	14.9	15.1	14.8	14.8	14.8	14.9
Triumph	14.8	14.7	14.4	14.9	14.4	14.7
Seeding rate mean	15.3	15.0	15.0	15.1	15.0	

LSD at 5% level

Varieties = .7

Rates = .2

Varieties within each rate = .3

Rates within each variety = .5

Variety	Bison	Cheyenne	Ottawa	Kaw	Pawnee	Triumph
Ranking	15.4	15.3	15.1	15.0	14.9	14.7

Rate	6	24	12	18	30
Ranking	15.3	15.1	15.0	15.0	15.0

Means underscored by the same line are not significantly (5% level) different.

Table 7. Sources of variation, degrees of freedom, and mean squares in analysis of variance of data for the plant spacing experiment.

Source	D. F.	Mean Squares					
		Yield (lb./A.)	Yield per plant (g.)	Heads per sq.ft.	Seeds per head	Seed weight (g./200)	Protein Percentage
Main plots							
Replications	3	845,471*	69.2*	195.8**	197.8*	.313	.090
Varieties (V)	5	1,343,484**	110.9**	37.8	440.4**	3.156*	7.442*
Error A	15	196,044	16.5	16.3	35.9	.425	.798
Sub plots							
Spacings (S)	3	2,104,284**	63.2**	353.8**	38.0	.507**	2.286**
V X S	15	21,840	5.4	1.5	11.2	.045	.491
Error B	54	35,632	3.2	2.4	25.7	.067	.298
Total	95						

* Significant at 5% level

** Significant at 1% level

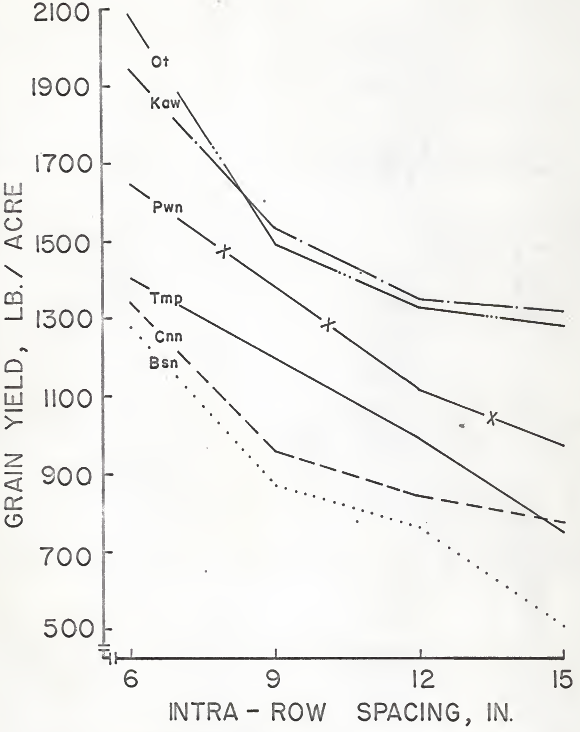

Figure 6. Influence of variety and plant spacing on grain yield.

Table 8. Influence of variety and plant spacing on grain yield (pounds per acre).

Variety	Intra-row spacing (inches) 6	9	12	15	Variety mean
Bison	1276	873	758	508	854
Cheyenne	1342	958	841	777	980
Kaw	1943	1533	1348	1318	1536
Ottawa	2084	1496	1326	1279	1547
Pawnee	1647	1386	1115	974	1281
Triumph	1403	1192	994	750	1085
Spacing mean	1615	1240	1064	934	

LSD at 5% level Varieties = 334

Spacings = 109

Variety	Ottawa	Kaw	Pawnee	Triumph	Cheyenne	Bison
Ranking	1547	1536	1281	1085	980	854

Spacing	6	9	12	15
Ranking	1615	1240	1064	934

Means underscored by the same line are not significantly (5% level) different.

acre as plant spacing increased. The largest decrease in yield for all varieties except Triumph and Pawnee occurred as spacing was increased from 6 to 9 inches. Grain yield of Triumph decreased about the same amount with each spacing increase. Yield of Pawnee dropped about the same from the 6 to 9 inch spacing as at the 9 to 12-inch spacing and decreased less as the spacing was increased from 12 to 15 inches.

Spacing means were all significantly different at the five per cent level. Yield decreased rapidly as the distance between plants was increased. The decrease in yield as the spacing was raised from 6 to 9 inches was over twice those occurring at the other two spacing increases. Variety x spacing interaction was not noted.

Yield Per Plant. Data on yield per plant is given in Figure 7 and Table 9. Differences in yield per plant due to both variety and plant spacing were significant at the one per cent level. Kaw and Ottawa per plant yields were significantly (five per cent level) higher than Triumph, Cheyenne, and Bison. Pawnee yield per plant did not differ significantly from Kaw, Ottawa, Triumph, and Cheyenne but was significantly higher than Bison. The differences between spacing means were all significant at the five per cent level. The increases in yield per plant as spacing was increased from 6 to 9 and from 9 to 12 inches were slightly greater than the yield increase occurring as spacing was increased from 12 to 15 inches.

The variety x spacing interaction was significant at the 10 per cent level and attributed largely to the inconsistent response of Bison and Triumph.

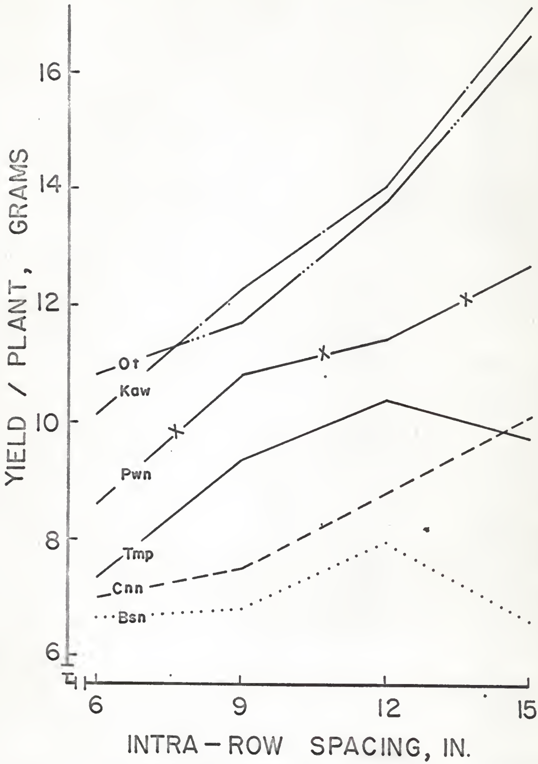

Figure 7. Influence of variety and plant spacing on grain yield per plant.

Table 9. Influence of variety and plant spacing on the yield per plant (grams).

Variety	Intra-row spacing (inches)				Variety mean
	6	9	12	15	
Bison	6.65	6.82	7.89	6.61	6.99
Cheyenne	6.99	7.49	8.76	10.12	8.34
Kaw	10.12	12.25	14.05	17.14	13.39
Ottawa	10.86	11.70	13.82	16.66	13.25
Pawnee	8.58	10.84	11.43	12.68	10.89
Triumph	7.31	9.32	10.36	9.77	9.19
Spacing mean	8.42	9.74	11.05	12.17	

LSD at 5% level Varieties = 3.06

Spacings = 1.04

Variety	Kaw	Ottawa	Pawnee	Triumph	Cheyenne	Bison
Ranking	13.39	13.25	10.89	9.19	8.34	6.99

Spacing	15	12	9	6
Ranking	12.17	11.05	9.74	8.42

Means underscored by the same line are not significantly (5% level) different.

Heads Per Square Foot. The influence of variety and spacing on heads per square foot is presented in Figure 8 and Table 10. Differences due to varieties were significant at the 10 per cent level. The ranking in order of decreasing heads per square foot was Pawnee, Cheyenne, Ottawa, Kaw, Triumph, and Bison. All varieties produced fewer heads per square foot as the distance between plants increased.

All spacing means were significantly different at the five per cent level. The number of heads per square foot decreased as the spacing increased. The reduction in the number of heads per square foot occurring when the distance between plants was increased from 6 to 9 inches was more than twice the reductions occurring as spacing was increased from 9 to 12 and 12 to 15 inches. There was no significant variety x spacing interaction.

Number Of Seeds Per Head. Data for this yield component appear in Figure 9 and Table 11. Varietal differences were significant at the one per cent level of probability. Ottawa had significantly (five per cent level) more seeds per head than the other varieties. Kaw had significantly more seeds per head than Bison and Cheyenne. Cheyenne produced significantly less seeds per head than all other varieties but Bison.

Differences in number of seeds per head due to spacing were not significant. There was no significant variety x spacing interaction.

Seed Weight. Seed weight data are shown in Figure 10 and Table 12. Seed weight of Kaw was significantly greater than all the other varieties. Triumph and Bison were not significantly

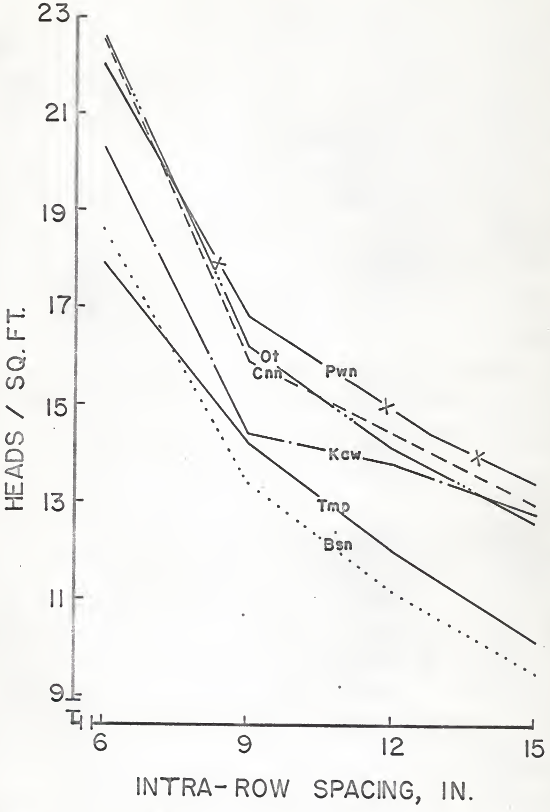

Figure 8. Influence of variety and plant spacing on number of heads per square foot.

Table 10. Influence of variety and plant spacing on the number of heads per square foot.

Variety	Intra-row spacing (inches)				Variety mean
	6	9	12	15	
Bison	18.6	13.4	11.2	9.5	13.2
Cheyenne	22.5	15.9	14.4	13.0	16.5
Kaw	20.3	14.4	13.8	12.8	15.3
Ottawa	22.6	16.1	14.1	12.6	16.3
Pawnee	22.0	16.8	14.4	13.4	16.6
Triumph	17.9	14.2	12.0	10.1	13.6
Spacing mean	20.6	15.1	13.3	11.9	

LSD at 5% level Spacings = .9

Variety	Pawnee	Cheyenne	Ottawa	Kaw	Triumph	Bison
Ranking	16.6	16.5	16.3	15.3	13.6	13.2

Spacing	6	9	12	15
Ranking	20.6	15.1	13.3	11.9

Means underscored by the same line are not significantly (5% level) different.

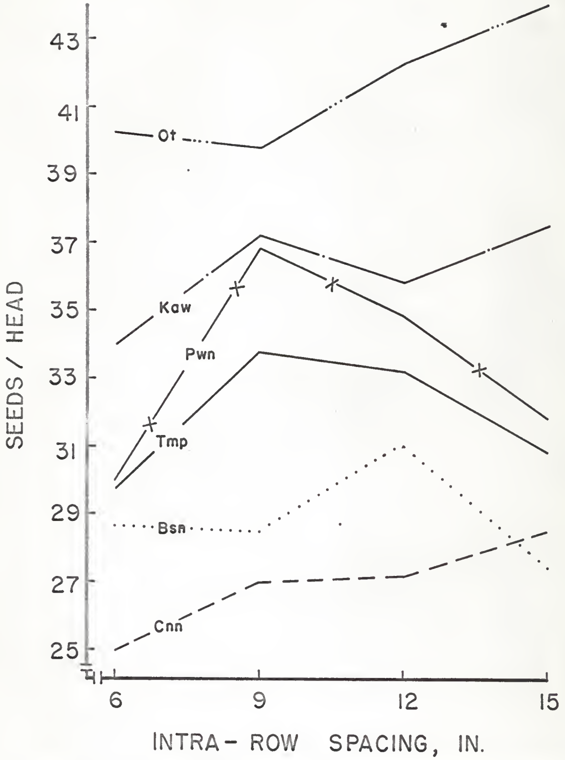

Figure 9. Influence of variety and plant spacing on number of seeds per head.

Table 11. Influence of variety and plant spacing on number of seeds per head.

Variety	Intra-row spacing (inches) 6	9	12	15	Variety mean
Bison	28.7	28.5	31.0	27.5	28.9
Cheyenne	25.0	27.0	27.2	28.5	26.9
Kaw	34.0	37.2	35.8	37.5	36.1
Ottawa	40.2	39.8	42.2	44.0	41.6
Pawnee	30.0	36.8	34.8	31.8	33.3
Triumph	29.8	33.8	33.2	30.8	31.9
Spacing mean	31.3	33.8	34.0	33.3	

LSD at 5% level Varieties = 4.5

Variety	Ottawa	Kaw	Pawnee	Triumph	Bison	Cheyenne
Ranking	41.6	36.1	33.3	31.9	28.9	26.9

Spacing	12	9	15	6
Ranking	34.0	33.8	33.3	31.3

Means underscored by the same line are not significantly (5% level) different.

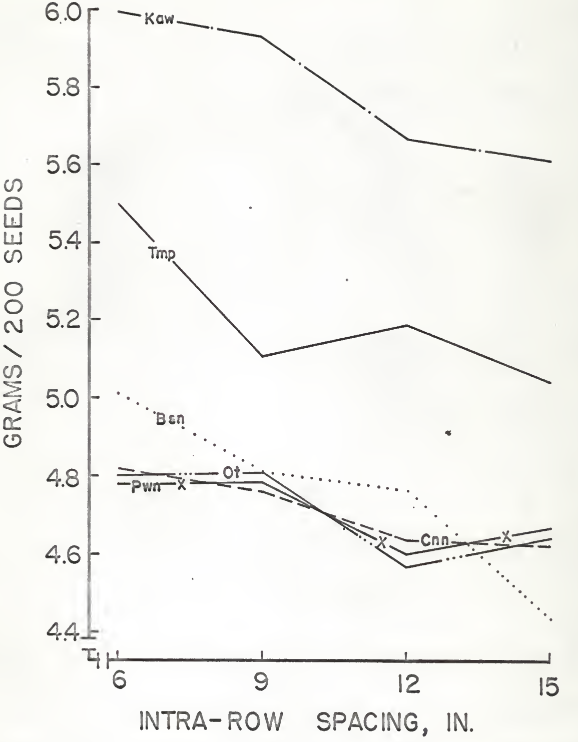

Figure 10. Influence of variety and plant spacing on seed weight.

Table 12. Influence of variety and plant spacing on the weight of 200 seeds (grams).

Variety	Intra-row spacing (inches)				Variety mean
	6	9	12	15	
Bison	5.11	4.81	4.76	4.43	4.78
Cheyenne	4.82	4.76	4.63	4.62	4.71
Kaw	5.99	5.93	5.67	5.61	5.80
Ottawa	4.80	4.81	4.57	4.64	4.71
Pawnee	4.77	4.78	4.60	4.67	4.71
Triumph	5.50	5.11	5.18	5.04	5.21
Spacing mean	5.16	5.03	4.90	4.84	

LSD at 5% level Varieties = .49

Spacings = .16

Variety	Kaw	Triumph	Bison	Cheyenne	Ottawa	Pawnee
Ranking	5.80	5.21	4.78	4.71	4.71	4.71

Spacing	6	9	12	15
Ranking	5.16	5.03	4.90	4.84

Means underscored by the same line are not significantly (5% level) different.

different; however, Triumph had significantly heavier seed than Cheyenne, Ottawa, and Pawnee. The seed weights of Bison, Cheyenne, Ottawa, and Pawnee were not significantly different. Bison, Cheyenne, and Kaw seed weights decreased with increased spacing. This trend was also shown to a lesser extent by Ottawa, Kaw, and Triumph.

Differences between spacing means were significant at the one per cent level. Seed weight decreased slightly with increased spacing. The variety x spacing interaction was insignificant.

Grain Protein Content. Figure 11 and Table 13 show Ottawa and Bison to have significantly (five per cent level) higher protein content than Cheyenne, Pawnee, and Triumph. Bison and Kaw were not significantly different. Kaw and Cheyenne were not significantly different, but Kaw protein percentage was significantly greater than Pawnee and Triumph. Ottawa and Triumph protein contents increased with each increase in plant spacing. Bison and Pawnee showed an inconsistent trend toward more protein with increased spacing. Kaw decreased in protein up to the 12-inch spacing and then increased at the 15-inch spacing. Cheyenne increased in protein up to the 12-inch spacing then decreased at the 15-inch spacing.

Spacing means differed at the one per cent level. Protein content increased as spacing increased. The variety x spacing interaction was significant at the 10 per cent level and was attributed to the inconsistent response of all the varieties except Ottawa and Triumph.

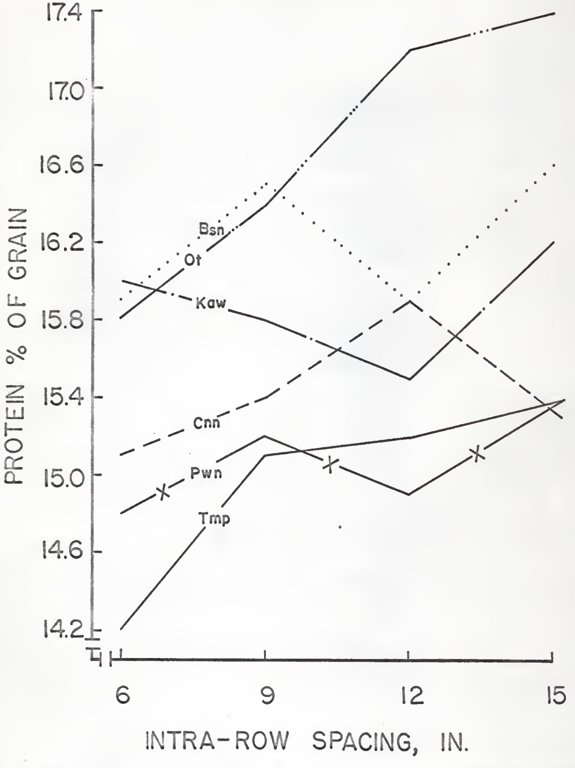

Figure 11. Influence of variety and plant spacing on protein percentage of grain.

Table 13. Influence of variety and plant spacing on the protein percentage of grain.

Variety	Intra-row spacing (inches) 6	9	12	15	Variety mean
Bison	15.9	16.5	15.9	16.6	16.2
Cheyenne	15.1	15.4	15.9	15.3	15.4
Kaw	16.0	15.8	15.5	16.2	15.9
Ottawa	15.8	16.4	17.2	17.4	16.7
Pawnee	14.8	15.2	14.9	15.4	15.1
Triumph	14.2	15.1	15.2	15.4	15.0
Spacing mean	15.3	15.7	15.8	16.0	

LSD at 5% level Varieties = .7

Spacings = .3

Variety	Ottawa	Bison	Kaw	Cheyenne	Pawnee	Triumph
Ranking	16.7	16.2	15.9	15.4	15.1	15.0

Spacing	15	12	9	6
Ranking	16.0	15.8	15.7	15.3

Means underscored by the same line are not significantly (5% level) different.

DISCUSSION

In general, all the varieties tested showed increased yield as plant density increased. The exceptions occurred in the seeding rate experiment where Bison had depressed yield at the 24 viable seeds per square foot rate and Cheyenne decreased in yield as the seeding rate was increased from 24 to 30 viable seeds per square foot. These yield decreases were caused by poor stands for these rates in two replications of Bison and one of Cheyenne. These poor stands were caused by errors in seeding, rodent damage, etc.

Yield per plant increased as plant spacing increased; however, the accompanying reduction in plant density resulted in reduced yield. Maximum yields were obtained at either 24 or 30 viable seeds per square foot. These optimum rates are similar to those reported by Ahmed (1), Georgeson (10), and Stickler (41) for this location but are slightly greater than those reported by Ten Eyck and Shoesmith (42).

The yield rankings for the two experiments were very similar. Pawnee and Triumph, and Cheyenne and Bison exchanged rank; however, their differences were insignificant at the five per cent level in both experiments. There was a highly significant (one per cent level) correlation ($r = .943$) between variety means of the two experiments, indicating that the relative yielding ability of varieties may possibly be predicted from space-planted trials. A previous study by Ahmed (1) conducted in 1961-62 did not show this similarity between the two experiments. This difference between the present and previous studies may be due largely to climatic

and seeding date differences. The seeding date in Ahmed's study was September 27 and 29, and fall growing conditions were conducive for extensive tillering. In the present study, a planting date of October 9 resulted in a little more than one-half the number of tillers as occurred in the previous study. Moisture was limited in the latter part of the season. Thus, in a season with considerable environmental stress there were rather large differences in yield between the varieties in both the seeding rate and plant spacing experiments and a relatively close correlation between the two. The rather favorable season in the previous study resulted in little yield differences between varieties in the seeding rate experiment and no significant yield differences between varieties in the plant spacing experiment and little correlation between the two.

Another point of interest regarding yield is the poor performance of Bison, Cheyenne, and Triumph at low plant densities and the ability of Kaw, Ottawa, and Pawnee to produce relatively high yields at low densities. This relationship in the seeding rate experiment could be largely due to the failure of Bison, Cheyenne, and Triumph to establish the desired stands. However, the same relationship occurred with yield per acre and yield per plant in the plant spacing experiment where desired stands were obtained by hand thinning.

The importance of linear, quadratic, and cubic effects of plant density on yield were determined by using orthogonal comparisons. Yield appeared to be largely a linear function of plant density, with the quadratic effect accounting for a much smaller

(but significant) portion of the treatment sum of squares.

The yield data from these experiments indicate the necessity of relatively high seeding rates for maximum yields of these six varieties and that there may be need for special emphasis on this point with Bison, Cheyenne, and Triumph.

Plant density had a marked influence on the number of heads per square foot. As the intra-row spacing was increased from six to nine inches, there was a sharp reduction in the number of heads per square foot. The reduction in heads per square foot was less as the spacing between plants was increased to 12 and 15 inches. In the seeding rate experiment, Ottawa produced more heads per square foot than all the other varieties while Pawnee and Kaw produced slightly less and Bison, Cheyenne, and Triumph produced the least. However, as the plant density decreased Pawnee produced the greatest number of heads per square foot as shown in the plant spacing experiment. Cheyenne also moved up in rank to produce about the same number of heads per square foot as Ottawa with both being only slightly less than Pawnee. These changes in rank indicate varietal differences in tillering response with different plant densities. Buffum (4), Grantham (12), and Percival (35) suggest that the inherent ability of a variety to produce mature tillers is most easily recognized when the competition between plants is eliminated by wide spacing between individual plants. In regard to this concept, the present study would indicate that of the varieties tested, Ottawa had the greatest capacity to maintain its inherent tillering ability as competition between plants increased, while the tillering of Cheyenne was greatly hampered by competition.

This difference may have been caused by the fact that Ottawa is well adapted to northeastern Kansas while Cheyenne is less well adapted.

In the seeding rate experiment, the number of seeds per head was not significantly influenced by variety. However, in the plant spacing experiment, there were marked differences among variety means. In both experiments, the number of seeds per head increased slightly with decreased plant density (significant in the seeding rate experiment and insignificant in the plant spacing experiment).

There was a significant variety x seeding rate interaction in the seeding rate experiment. This was caused by the inconsistent response of all the varieties except Ottawa and Pawnee.

In the present study, the number of seeds per head in both experiments was almost twice the number reported in the earlier study by Ahmed (1). This was evidently associated with the greatly reduced tillering occurring in the present study. The results of these experiments are in agreement with the literature in regard to the influence of plant density or the number of heads per square foot on the number of seeds per head (5,8,35,41).

Variety seed weight differences were significant in both experiments. Differences due to plant spacing were significant while differences due to seeding rate were insignificant. In general, seed weight increased with increased density. This was probably due to the smaller number of seeds per head occurring at the higher plant densities.

Simple and partial correlation coefficients for yield and

yield components are shown in Table 14. The partial correlation coefficients, which hold remaining components constant, show a significant positive correlation between yield and all three of the yield components in both experiments. The greatest correlation was between yield and the number of heads per square foot in both experiments. This emphasizes the importance of establishing stands which will furnish a large number of heads per square foot. There were no significant correlations between any of the yield components.

Another point of interest is the varietal differences in the contribution of the yield components to yield. The yields of Ottawa and Kaw were not significantly different in either experiment. However, Ottawa produced a greater number of heads per square foot and seeds per head than did Kaw in both experiments. Thus, the very high seed weight of Kaw enabled it to equal the yield of Ottawa. Pawnee ranked high in the number of heads per square foot and the number of seeds per head, but its low seed weight resulted in only average yield. In the plant spacing experiment, Cheyenne ranked second in the number of heads per square foot but ranked fifth in yield because of low ranking in both the number of seeds per head and seed weight. All the yield components of Bison ranked low with resultant poor yield in both experiments.

Varietal differences in grain protein content were much more evident in the plant spacing experiment than in the seeding rate experiment. Protein differences due to plant density were significant in both experiments. Protein content of the grain increased with decreased plant density. This was evidently because of the greater supply of soil nitrogen available per plant at the lower plant densities.

Table 14. Simple and partial correlation coefficients for yield and yield components.

	Correlation coefficients	
	Seeding rate experiment	Spacing experiment
Yield vs. number of heads per sq. ft.	.835**	.782**
Yield vs. number of heads per sq. ft., independent of number of seeds per head and seed weight	.936**	.947**
Yield vs. number of seed per head	-.229	.513*
Yield vs. number of seeds per head, independent of number of heads per sq. ft. and seed weight	.379*	.879**
Yield vs. seed weight	.414*	.467*
Yield vs. seed weight, independent of number of heads per sq. ft. and number of seeds per head	.854**	.764**
Number of heads per sq. ft. vs. number of seeds per head	-.298	-.045
Number of heads per sq. ft. vs. number of seeds per head, independent of seed weight	-.303	-.024
Number of heads per sq. ft. vs. seed weight	-.021	.151
Number of heads per sq. ft. vs. seed weight, independent of number of seeds per head	-.101	.219
Number of seeds per head vs. seed weight	-.244	.144
Number of seeds per head vs. seed weight, independent of heads per sq. ft.	-.262	.153

* Significant at 5% level

** Significant at 1% level

SUMMARY AND CONCLUSIONS

In 1962-63 a seeding rate and plant spacing study with six winter wheat varieties was conducted on the Agronomy Farm of the Kansas Agricultural Experiment Station, Manhattan, Kansas. One experiment consisted of seeding rates of 6, 12, 18, 24, and 30 viable seeds per square foot. Plant spacings of 6, 9, 12, and 15 inches in the row were employed in the other test. Twelve-inch rows were used in both tests. The varieties, Bison, Cheyenne, Kaw, Ottawa, Pawnee, and Triumph, were included in both experiments.

Significant differences in grain yield occurred among varieties in both experiments. The lowest yields in both experiments were those of Bison and Cheyenne. Ottawa and Kaw produced the highest yields in both experiments. The correlation of the variety means between the two experiments was highly significant ($r = .943$). The similar varietal response of the two tests suggests that varietal yield performance in space-planted trials can sometimes be a good indication of field performance.

The seeding rate experiment showed that maximum yield of all six varieties was highly dependent on relatively high seeding rates (6 or 7 pecks per acre). In both experiments, low plant density restricted the yield of Bison, Cheyenne, and Triumph more than the other three varieties. The results of this study suggest the desirability of seeding rates which result in high plant density and that there may be need of special emphasis on this point with certain varieties.

The number of heads per square foot increased with increased plant density and was closely associated with yield in both

experiments. The number of heads per square foot was significantly influenced by variety in the seeding rate test while the varietal differences were not significant in the plant spacing test.

The number of seeds per head increased slightly with decreased plant density in both experiments (significant only in the seeding rate experiment). The varietal means differed significantly in the plant spacing test and were insignificant in the seeding rate experiment.

Seed weight increased slightly with increased plant density in both experiments (significant only in the plant spacing experiment). Varietal differences in seed weight were significant in both experiments.

All three yield components showed a significant positive correlation with yield in both experiments. There were no significant correlations among the yield components.

Protein content of the grain increased significantly with decreased plant density in both experiments. Varietal differences in protein content were significant in both experiments.

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RESPONSE OF CERTAIN WINTER WHEAT VARIETIES
TO STAND DENSITY

by

JIMMY MABRY

B. S., Texas Technological College, 1962

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

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1964

There is a need for determining if the old well-established seeding rates are satisfactory for the newer varieties of winter wheat. Possible differences in the seeding rate requirements of varieties, whether new or old, are also worthy of investigation. The performance of varieties in space planted studies as related to field performance is of particular interest to the plant breeder.

Therefore, a seeding rate and plant spacing study with six winter wheat varieties was conducted on the Agronomy Farm of the Kansas Agricultural Experiment Station, Manhattan, Kansas. One experiment consisted of seeding rates of 6, 12, 18, 24, and 30 viable seeds per square foot. Plant spacings of 6, 9, 12, and 15 inches in the row were used in another test. Twelve-inch rows were used in both tests. The varieties, Bison, Cheyenne, Kaw, Ottawa, Pawnee, and Triumph, were included in both experiments.

Significant differences in grain yield occurred among varieties in both experiments. Ottawa and Kaw produced the highest yields in both tests. The lowest yield in both experiments were those of Bison and Cheyenne. The correlation of the variety means between the two experiments was highly significant ($r = .943$). The similar varietal response of the two tests suggests that varietal yield performance in space planted trials may be a good indication of field performance.

The seeding rate experiment showed that maximum yield of all six varieties was highly dependent on relatively high seeding rates (6 or 7 pecks per acre). In both experiments, low plant density restricted the yield of Bison, Cheyenne, and Triumph more than the other three varieties. The results of this study suggest

the desirability of seeding rates which result in high plant density and that there may be need of special emphasis on this point with certain varieties.

The number of heads per square foot increased with increased plant density and was closely associated with yield in both experiments. The number of heads per square foot was significantly influenced by variety in the seeding rate test, but varietal differences were not significant in the plant spacing test.

The number of seeds per head increased slightly with decreased plant density in both experiments (significant only in the seeding rate experiment). The varietal means differed significantly in the plant spacing test and were insignificant in the seeding rate experiment.

Seed weight increased slightly with increased plant density in both experiments (significant in the plant spacing experiment and insignificant in the seeding rate experiment). Varietal differences in seed weight were significant in both experiments.

All three yield components showed a significant positive correlation with yield in both experiments. There were no significant correlations among the yield components.

Protein content of the grain increased significantly with decreased plant density in both experiments. Varietal differences in protein content were significant in both experiments.